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FOR THE COMMANDER

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DIODE-LASER TRANSMITTER DEVELOPMENT FOR SPACE-BASED HETERODYNE COMMUNICATION

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ABSTRACT

An optical transmitter, based on four redundant 30-mW GaAlAs diode lasers operating at 0.86 µm, is being developed for an experiment in space-based heterodyne communication. Key optical, mechanical, and electrical components of the transmitter have been fabricated and tested in prototype form. A module which includes the laser, collimator, and electronics has been assembled which yields a wavefront quality of better than λ/30 over a 24°C temperature range. The laser and its four-element collimator have been shaken independently at 49 g (rms) without degradation in performance. The transmitter will weigh less than 2.3 kg and consume less than 4.2 W during normal operation.

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1. INTRODUCTION

For the past several years, we have been developing a diode-laser transmitter as part of an experiment in space-based optical communication.[1] Our goal has been to build a compact, robust, optical, mechanical, and electrical assembly for integration into a flight package which carries a 20-cm-diam. telescope. The experiment employs 4-ary FSK modulation at the transmitter and heterodyne detection at the receiver, with a maximum data rate of 220 Mb/s. In accordance with our system design,[2,3] the transmitter must: (a) emit a collimated beam of high optical quality, (b) not substantially degrade the electro-optical characteristics of the laser, (c) allow frequency modulation of the laser, (d) provide redundancy in the laser sources, and (e) survive launch and operate in the spacecraft environment.

The transmitter is based on four redundant GaAlAs diode lasers which operate near 0.86 μm (see Table I for typical laser operating characteristics). The transmitter also contains collimation and beam-shaping optics, foil heaters, and a radiator for temperature control as well as electronics for DC biasing, switching, and impedance matching.

The transmitter is to be integrated into a satellite package which includes, among other hardware, a temperature and current controller for the transmitter, a single modulator with one equalizer for each laser, a transmitter diagnostics module, and a source select mirror. When integrated into the package, the beam from the transmitter will be intercepted by the source select mirror which redirects the beam to one of three possible beam paths. One of these directions is toward the on-board diagnostics module which is used as a sensor for setting laser current and temperature.[3] The other paths are both toward the 20-cm telescope.[2]

TABLE I

Typical Characteristics of Hitachi Channeled-Substrate Planar GaAlAs Laser (HL8314E, Modified)

Wavelength	0.86 μm
Optical Power	30 mW
DC Bias	120 mA
Polarization	Linear
DC Responsivity	3 GHz/mA
Temperature Tuning	30 GHz/°C (within single mode)

A key requirement of the transmitter is that focus be maintained over the temperature range of 10° to 30°C. This range is necessary to insure that a selected laser can operate at a specific wavelength, even after aging of the laser's characteristics. Moreover, once a particular wavelength is reached, the laser temperature must be stabilized to $\pm$0.001°C in order to minimize the uncertainty in the heterodyne receiver's frequency acquisition system.

To be useful in space applications, the transmitter must be able to survive spacecraft launch without degradation in performance. A major concern is the vibration level to which the transmitter will be exposed. We have designed the transmitter to withstand three exposures to a random vibration excitation in each of three axes for 2 min at levels up to 49 g (rms). Additional requirements on the transmitter are summarized in Table II.

TABLE II

Transmitter Specifications

Optical Power	25.1 mW (min)
Wavelength	8630 to 8660 Å
Wavefront Quality	Strehl ≥ 0.9 (λ/20 rms, or better)
Polarization	Linear (purity > 99:1)
Beam Profile	Gaussian, 4.6-mm diameter at $1/e^2$
Beam Cross Section	Circular (ellipticity < 0.05)
Linewidth	7 MHz or better
FSK Waveform	Transition time (10 to 90 percent) < 1 ns

2. TRANSMITTER DESIGN

The transmitter design is based on four independent source assemblies, each of which contains a laser, collimator, biasing electronics, modulation port, and part of a thermal control circuit.[4] The transmitter also contains four 45° fold mirrors for beam pointing as well as four pairs of anamorphic prisms with a compression ratio of 2.4:1 for beam circularization and steering, as shown schematically in Figure 1. Each source assembly is collimated and tested before integration into the transmitter.

The source assemblies are mounted in a titanium support structure, with two sources secured to the top flange and two to the bottom flange (see Figures 2 and 3). The transmitter is attached to its mounting surface at three points by means of titanium struts of low cross-sectional area which provide the required thermal isolation. An aluminum radiator with optical solar reflector tiles is kinematically mounted to the housing using a three-point flexure arrangement. A cover placed over the complete assembly provides contamination protection and also supports a multilayer thermal insulation blanket.

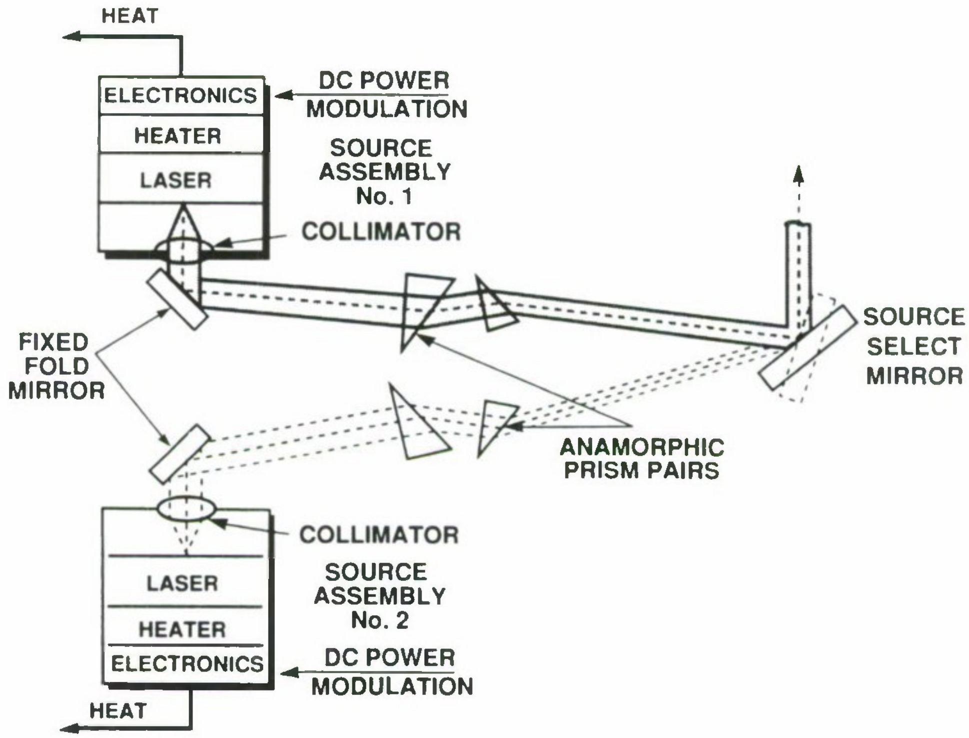

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Figure 1. Schematic of the transmitter optical train. Not shown are two additional source assemblies whose beams also intersect at the source select mirror. The source select mirror rotates to direct the enabled beam into the proper path.

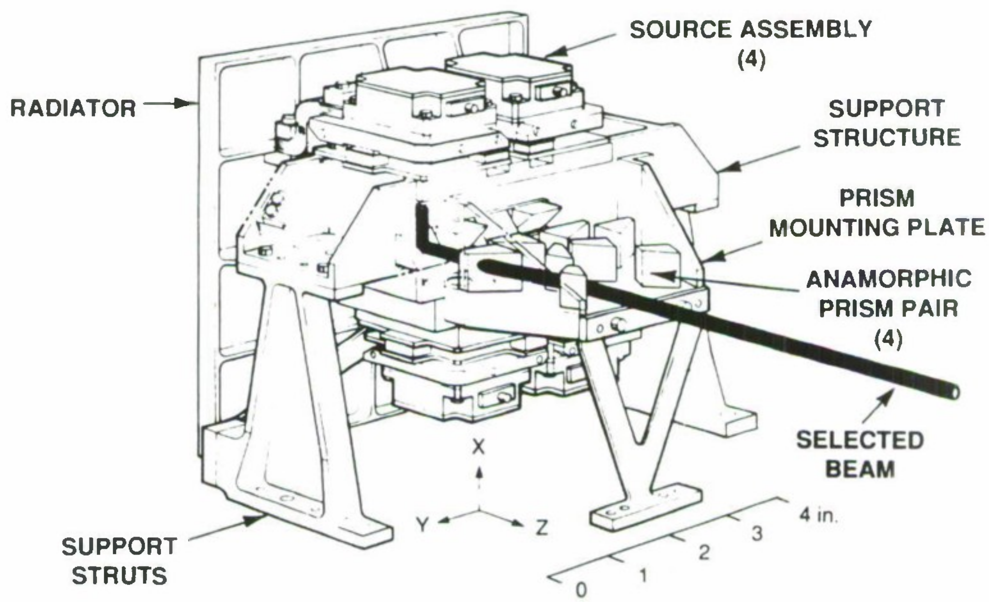

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Figure 2. View of the transmitter without environmental cover.

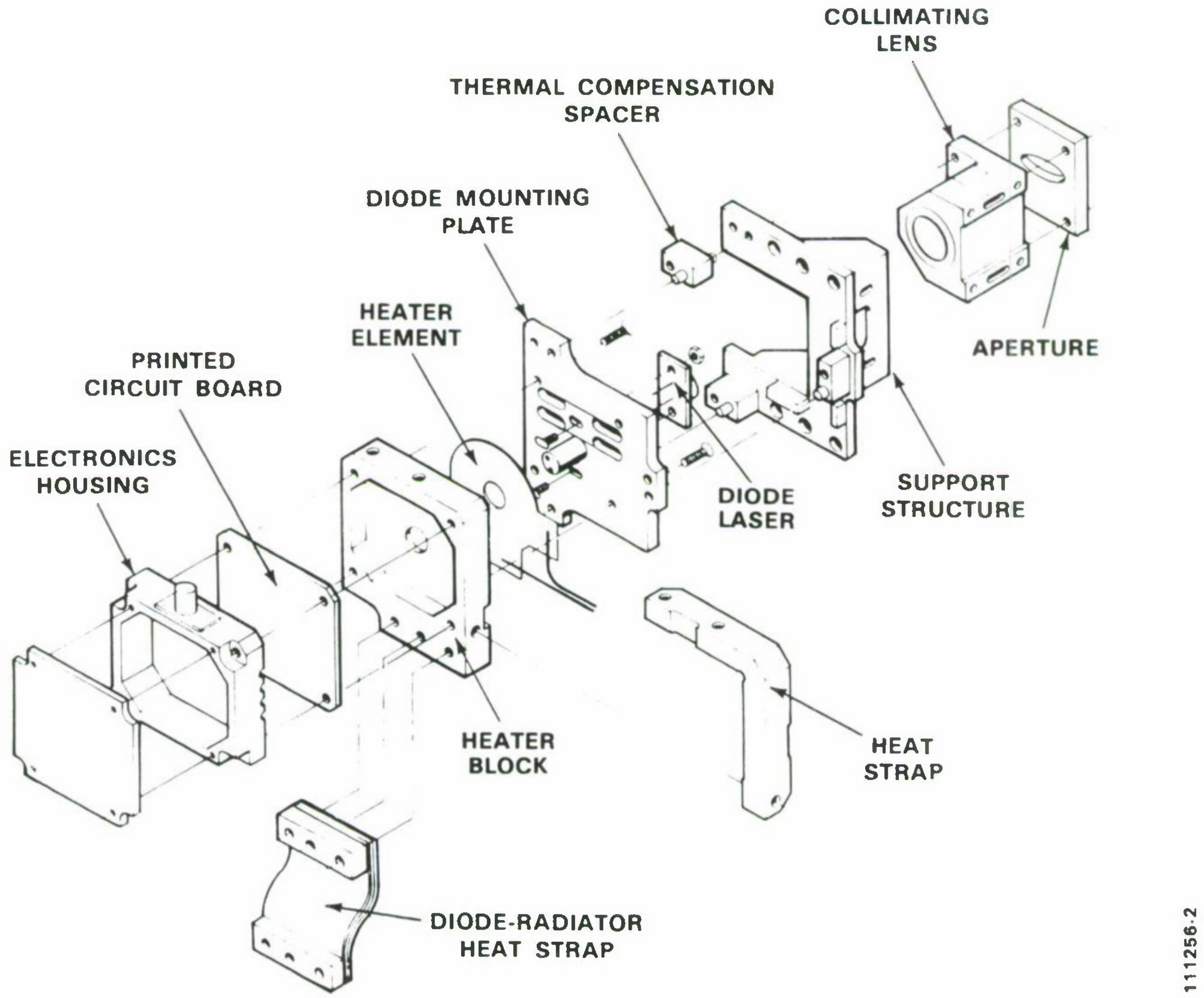

Figure 3. Exploded view of the source assembly.

In order to maintain the good wavefront quality necessary for distant communication, the laser must remain in the focal plane of the collimator with high tolerance, due to the low f-number of the collimator. Our design goal has been to maintain the laser within 0.7 μm of the focal plane. To achieve this, the expected changes in the back focal length of the collimator over temperature were calculated using the Code V optical design program.[5] These changes include the effects of lens de-spacing due to housing thermal expansion, lens curvature changes due to glass thermal expansion, and changes in the glass' index of refraction. Similarly, by knowing the geometry and materials used in the diode mounting post construction, the post's change in length relative to the mounting flange can be estimated. By optimizing the length of the spacer placed between the collimator and diode, as well as the material used, the combined thermal defocus can be made zero. For our system, 7.1-mm-long Invar spacers are used.

In order to maintain precise control of the laser temperature, a controlled current is sent through a foil heater which is located on one side of the titanium diode mounting plate, as shown in Figure 3. A surface-mounted thermistor is located next to the diode for use in the temperature control loop. In addition to the heaters located in the four source assemblies, the transmitter also contains two frame heaters which help minimize thermal gradients which can alter beam pointing. All six heaters operate whenever any laser is operating in order to minimize gradients and to eliminate the need for heater switching circuitry. With its own radiator and heaters and with thermally isolating titanium legs, the transmitter is essentially thermally independent of the rest of the satellite package.

The completed transmitter will weigh less than 2.3 kg and consume between 1 and 4.2 W during communication sessions. Approximately 12 W is necessary when the transmitter temperature must be raised significantly in a short time. Such a change would be required, for example, when switching from a laser which operates at 15°C to one which operates at 25°C. The volume occupied by the transmitter is approximately 5000 cm^3.

3. TEST RESULTS

Currently, twelve prototype source assemblies have been constructed and utilized in optical, electrical, and thermal tests. The optical tests have measured wavefront quality, transmission, and linewidth broadening; the electrical tests have included modulation transfer function and input impedance; and the thermal tests have included frequency stability. To date, random vibration tests have been performed independently on the collimator and laser.

We have tested the optical quality of eleven collimators for wavefront quality and transmission. In order to maximize wavefront quality, we have carefully aligned each collimator's position with respect to the laser and obtained the wavefront phase map interferometrically. The alignment has been accomplished with a fixture developed at Lincoln Laboratory which allows independent three-axis motion of the collimator with respect to the laser. With this fixture, 0.1-μm positioning resolution is possible.

A wavefront quality over a 5-mm aperture of $\lambda/40$ has been achieved for the entire optical test system which includes the laser, collimator, an anamorphic prism pair, and a fold flat. This corresponds to a Strehl ratio of 0.97 — 25 percent of the first batch of collimators have yielded wavefront quality at this level; 75 percent of the collimators have yielded Strehl ratios of 0.94 or greater. It should be noted that we have not observed frequent occurrences of laser astigmatism which, of course, could preclude the achievement of a high wavefront quality with our optical design. We believe that this is due to the fact that our CSP lasers are primarily index guided, as opposed to gain-guided lasers.

A measurement was made of the wavefront quality as a function of source assembly temperature, with results shown in Figure 4. Had there been no compensation spacers in the source assembly, we would have expected the wavefront to deteriorate rapidly at the extremes of the temperature range.

The transmission through the collimator was measured by moving the collimator in and out of the beam in front of a power meter. All collimators measured exhibited transmission of greater than 97 percent (–0.13 dB). The small loss can be attributed approximately equally to attenuation in the SF6 glass

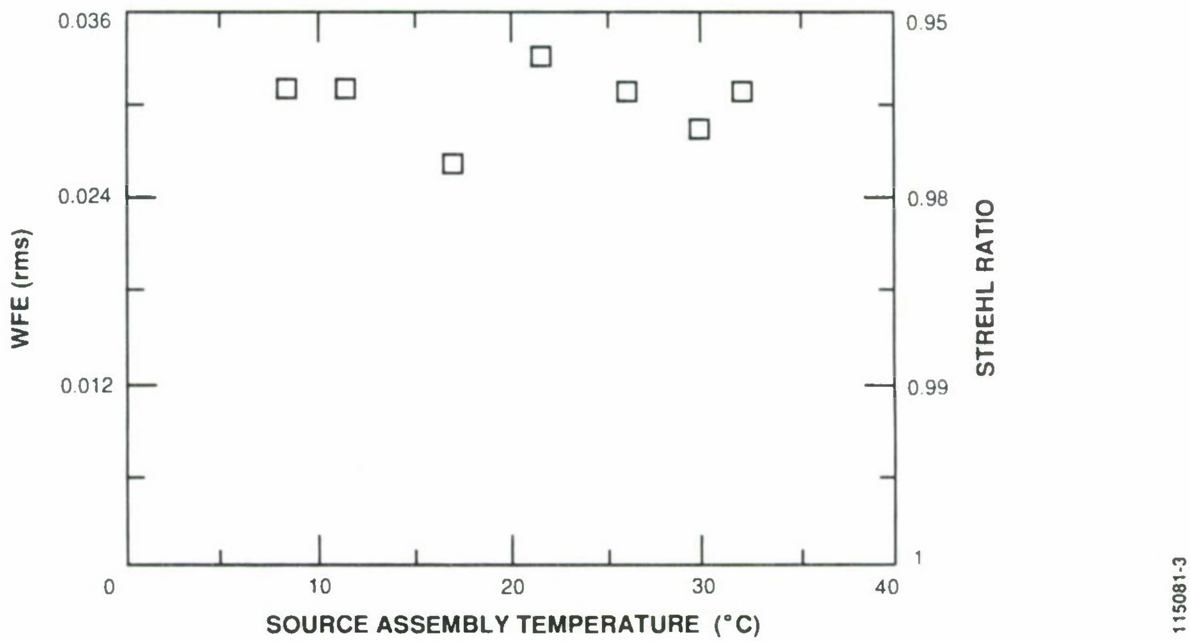

Figure 4. Wavefront quality vs source assembly temperature. The laser chip temperature remained approximately 20°C above the source assembly temperature.

and to reflection loss from the eight surfaces within the collimator. However, it should be pointed out that there is additional loss of 0.4 dB due to beam truncation when the f/1.1 collimator is aligned to the laser. This amount of truncation loss was chosen in conjunction with the design of the Dall-Kirkham telescope which the transmitter will feed.[6,7]

Feedback into the transmitting laser is not desirable in a heterodyne system because of the increase in laser linewidth that it causes. We have observed that feedback of less than –60 dB generally does not yield a discernible increase in laser linewidth. We have not observed an increase in laser linewidth due to feedback from the collimator, although we have not yet tested for feedback with our narrowest linewidth lasers.

Measurements of the modulation port input impedance have shown a return loss of better than 10 dB up to a frequency of 1 GHz. The high frequency response of the source assembly is limited by parasitic inductance in the laser package. Modulation transfer functions have been measured in order to construct an equalizer for each laser.

In order to check the stability of the entire thermal control system, the frequency of a beam emitted by a source assembly was monitored on a Fabry-Perot etalon. The center frequency was held constant to better than 5 MHz over a 60-s interval. Given the tuning rate of the laser with temperature, this implies a temperature stability of 100 to 200 μ°C, which is well within our requirements.

In order to gain confidence in the robustness of the transmitter, we have shaken two key components (the laser and the collimator) at the transmitter's required vibration test level. Neither the performance of the collimator nor laser was degraded by a 2-min shake at 49 g (rms). In the future, we expect to shake an entire source assembly and then the complete transmitter.

4. SUMMARY

We have fabricated and tested key components of a diode-laser transmitter for communication from a space-based platform. The optical and electrical performance of prototype assemblies exceeds that required for our communication system. The transmitter design is compact, and key components have been demonstrated to be robust. Redundancy is provided with four independent lasers, each with its own optical train. The transmitter is expected to maintain its high wavefront quality over a large temperature range due to an athermal focus design.

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